A Twist on the Sequence Stratigraphic Model: Climate Induced Incision with a Sea Level Assist

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Abstract

The sequence stratigraphy of Middle to Upper Pennsylvanian strata in the Appalachian Basin is complex, partly owing to the icehouse co-response to climate and sea level change during the late Paleozoic. The Breathitt Group resembles a traditional marine-to-terrestrial sequence stratigraphic model. The overlying Conemaugh Group also exhibits sequences, but they are more fluvial-dominated. Sequence stratigraphy largely presumes sea-level drive for sequences and accommodation. We present a model that is driven by both sea level and climate. We hypothesize that once the land surface is built up high enough above the water table, it is not required that sea level drop to induce valley incision, and in fact there is no evidence for a shelf slope break that would promote incision. Instead, we offer that climate change may be the main driver of valley incision.

This model is tested using strata in the Breathitt and Conemaugh Groups in the Northern and Central Appalachian Basin. Measured sections along a basin cross section in outcrop and 3D models built from UAV photographs help reveal this past environment to address the potential of climate change as a sequence driver.

The Breathitt to Conemaugh Group shift records a composite of sequences that are a progradational basin-fill and define a switch from a mixed marine and fluvial to fluvial fill. The Conemaugh sequences record upward shifts from a low-accommodation, valley-incised tributive to a high-accommodation, un-incised distributive systems tract. As a marine transgression tops the low-accommodation valleys below, it lays a basal peat which floods the tributive system. Next, the rivers in the distributive fluvial system prograde and push out the shore, as well as build a slope above sea level. This aggradation creates an elevated coastal prism. Continued progradation creates the elevation needed for valley incision, but this progradation need not cause incision, even if sea level falls. A climate change will eventually spur water table reduction owing to a locally drier climate, or an upstream water-sediment ratio change. Valley incision begins at that time, and possibly with no change in sea level. In this model, regression with or without sea level drop sets up the conditions needed for valley incision, but does not cause incision itself. Incision waits for adequate climate change to generate buffer valleys. The valleys record regression but are climate driven and do not have to define sea-level change.

Study Area

The Appalachian Basin is a foreland basin that spans from New York to Alabama (Figure 1). The basin is commonly divided into a northern, central, and southern region. The yellow star on the map (Figure 1) lies on the border between the northern and central Appalachian Basin, and represents the approximate area of study for this project.

Figure 1: Location of the Appalachian Basin within the United States. Image modified from the Appalachian Basin Data Group.

The five outcrops used in this study are road-cuts located along Kentucky State Route 23 and West Virginia State Route 52, between the towns of Prichard, West Virginia, and Louisa, Kentucky (Figure 2). The Big Sandy River forms the border between Kentucky and West Virginia. The road-cuts display strata from the underlying Breathitt Group and overlying Conemaugh Group. WV-1 and WV-2 are located in West Virginia and are stratigraphically higher than the three outcrops in Kentucky: K-2, K-3, and K-4. The road-cuts range from 50 to 100 meters in height, and they average approximately one kilometer in length. Straight line distance from the northernmost outcrop to the southernmost outcrop is about 13 kilometers, and the five outcrops combined allow for about 20% exposure when looking at a strike section of the basin (Figure 3).

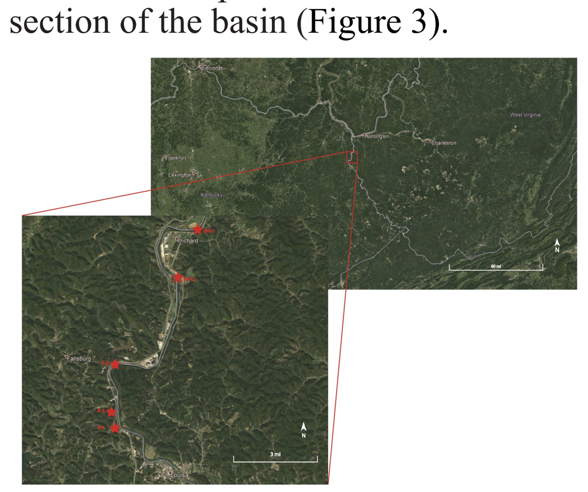


Figure 2: Location of areas of study within the Appalachian Basin. Images modified from Google Earth.

Figure 3: Strike section showing outcrop exposure within the Appalachian Basin. Straight line distance from northernmost to southernmost outcrop is about 13 kilometers. Image modified from Google Earth.

Depositional Environment

The construction of the Appalachian Basin is related to the Acadian, Taconic, and Alleghenian-Variscan orogenies that occurred as Gondwana collided with the eastern edge of Laurasia. The Alleghenian-Variscan orogeny was active during Pennsylvanian basin filling, and created accommodation in the basin as subsidence occurred (Thomas, 1995; Chesnut, 1991; Greb et al., 2008) (Figures 4 and 5).

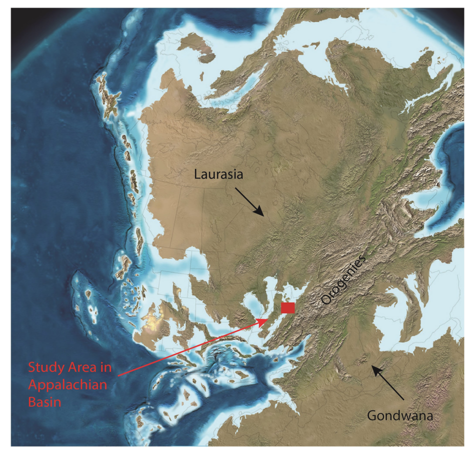


Figure 4: Map showing the collision of Gondwana into Laurasia. The red box indicates study area. Modified from Blakey.

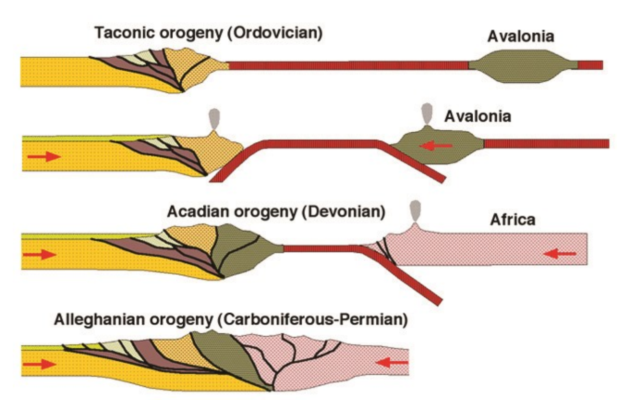


Figure 5: Cross-section view of the collision of Gondwana into Laurasia.

The Pennsylvanian was an icehouse/glacial period, but the Appalachian Basin was located 5° to 10° south of the Equator within the tropics (Scotese, 1994; Heckel, 1995). The basin was rotated about 40° clockwise from its current location (Scotese, 1994; Greb et al., 2009) (Figure 6). Throughout the Middle Pennsylvanian, the climate was wet and humid. During the Late Pennsylvanian Period, climate transitioned to more seasonally wet and dry (Cecil, 1990; Greb et al., 2009).

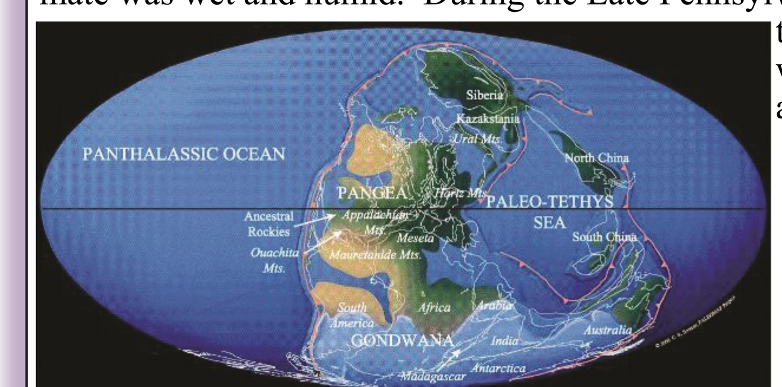


Figure 6: Map of the world during the Pennsylvanian Period. Note that the Appalachian Basin sits just south of the Equator.

Shallow seas from the west (the inland Midcontinent sea) inundated the Appalachian Basin numerous times during basin filling (Scotese, 1994; Greb et al., 2009) (Figure 4). While the Breathitt Group exhibits a more traditional mixed marine and fluvial basin fill, the overlying Conemaugh Group displays fluvial dominant sequences.

The Problem

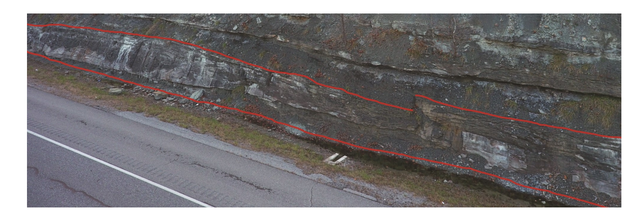
It is well-documented in the literature that lowering sea level stimulates valley incision. (e.g. Busch and Rollins, 1984; Greb et al., 2008; Heckel, 1995; Nadon and Kelley, 2004). However, while sequence stratigraphy often presumes a drop in base level as the inducer for valley incision, other possible motives for incision are not widely considered. This study addresses the possibility that valley incision is driven by both sea level and climate. I propose that the five outcrops in this study offer a great opportunity to test whether or not climate plays a significant role in prompting valley incision because the facies displayed in the outcrops record the various changes in water table level, which in turn record a change in climate.

Description of K4 Facies

Amalgamated sand channels in incised valley- low accommodation channels cut into each other and stack to fill an incised valley. Channels often display parallel laminations and/or cross bedding.

Coal/Carbonaceous shale- dark colored, carbonized plant matter. Forms in sheets that thin and thicken laterally.

Delta Front- amalgamated distributary channels and subaerial splays that form a thick sand body with a lobate structure, cross bedding and burrows.



Isolated sand channels/sheets in floodplain lake- heterolithic fill consisting of isolated channels in laminated siltstone that forms during high accommodation. Channels often display laminations and/or cross bedding.

Paleosol- floodplain that ranges from well-drained to poorly-drained. Red color indicates well-drained and oxidized floodplain, while gray, purple and yellow colors indicate poorly-drained floodplain. Usually displays non-laminated and hackly appearance, with plant fragments and/or rooting.

3D Model of Outcrop K4

Figure 7: Outcrop K4. Top picture is an unaltered orthomosaic, and the bottom photo is interpreted to show the major facies/depositional environments. Height of Terrace 1 in both photos is 14.6 meters.

Legend of Facies Interpretations

- Amalgamated sand channels in incised valley
- Coal/Carbonaceous Shale
- Delta Front
- Isolated sand channels/sheets in floodplain lake
- Paleosol

Data Collection

Measured sections and three dimensional models of the five road-cuts help to address the possibility that climate change is a sequence driver.

The measured sections are used to assist in understanding the depositional environment, changes in sediment type, and changes in sedimentation rate. These sections are also used to identify a set of key lithofacies. A minimum of two sections were measured on each outcrop in order to develop a cross-section across the strike of the basin in the study interval.

Photographs were taken of the outcrops using a DJI Phantom 4 Pro+ Quadcopter. The photos are stitched together to create three dimensional renderings of the outcrops using Agisoft Photoscanner software. The three dimensional models are helpful when mapping the architecture of the strata. Figure 7 is an example of an orthomosaic derived from one of the three dimensional models.

Conclusions

- It is evident that a climate signature is recorded in the five outcrops observed in this study. Of particular interest is the channel and valley incision that occurs. I propose that not only does a drier climate (and therefore a locally lower water table) promote valley incision, but that a drier climate will result in a larger incision. This incision happens without regard to base level.
- It is known that climate transitioned from ever-wet in the Middle Pennsylvanian to seasonally wet and dry during the Late Pennsylvanian (Cecil, 1990; Greb et al., 2009). The increasingly drier climate is evidenced in outcrop by a larger number of well-drained (red in color) paleosols in the outcrops that are stratigraphically higher. These times of locally drier climate may have been enough to lower the water table and spur valley incision within the basin.
- A change in climate upstream of the drainage basin would change the sediment/water ratio and therefore affects the type of fill that reaches the basin. If more water reaches the basin, owing to a wetter upstream climate, a greater amount of valley incision should result. Conversely, if more sediment reaches the basin, owing to a drier upstream climate, the basin should fill instead of incise. Additionally, the upstream change in climate may or may not be associated with glacial waxing and waning. A warmer climate is typically associated with a wetter climate, so when global temperatures were warmer, glaciers melted, there was abundant rainfall and a large amount of water flushed through the basin. When global temperatures were cooler, glaciers grew, a drier climate persisted, and erosion upstream allowed a large amount of sediment to reach the basin.

References

Busch, R.M., and Rollins, H.B., 1984, "Correlation of Carboniferous Strata using a Hierarchy of Transgressive-Regressive Units." Geology, vol. 12, no. 8, pp. 471, doi:10.1130/00917613(1984)12<471:COCSUA>2.0.CO;2.

Cecil, C.B., 1990, "Paleoclimate Controls on Stratigraphic Repetition of Chemical and Siliciclastic Rocks." Geology, vol. 18, no. 6, pp. 533, doi:10.1130/0091 7613(1990)018<0533:PCOSRO>2.3.CO;2.

Chesnut, D.R., Jr., 1991, Paleontological survey of the Eastern Kentucky Coal Field: Part 1— Invertebrates: Kentucky Geological Survey, ser. 11, Information Circular 36, 71 p.

Greb, S.F., Pashin, J.C., Martino, R.L., and Eble, C.F., 2008, Appalachian sedimentary cycles during the Pennsylvanian: Changing influences of sea level, climate, and tectonics, in Fielding, C.R., Frank, T.D., and Isbell, J.L., eds., Resolving the late Paleozoic ice age in time and space: Geological Society of America Special Paper 144, p. 235–248.

Greb, S.F., Chesnut, D.R., Jr., Eble, C.F., and Blake, B.M., 2009, "4: The Pennsylvanian of the Appalachian Basin." Kentucky Geological Survey Special Publication 10 12th ser. p. 32-45. Web.

Heckel, P.H., 1995, Glacial-eustatic base-level-climatic model for late Middle to Late Pennsylvanian coalbed formation in the Appalachian Basin: Journal of Sedimentary Research, v. B65, no. 3, p. 348–356.

Nadon, G.C., Kelly, R.R., 2004, The constraints of glacial eustasy and low accommodation on sequence stratigraphic interpretations of Pennsylvanian strata, Conemaugh Group, Appalachian basin, U.S.A. Am. Assoc. Pet. Geol. Stud. Geol. 51, 29–44.

Scotese, C.R., 1994, Carboniferous paleocontinental reconstructions, in Cecil, C.B., and Edgar, N.T., eds., Predictive stratigraphic analysis—Concept and application: U.S. Geological Survey Bulletin 2110, p. 3–6.

Thomas, W.A., 1995, Diachronous thrust loading and fault partitioning of the Black Warrior foreland basin within the Alabama recess of the late Paleozoic Appalachian-Ouachita thrust belt: Society of Economic Paleontologists and Mineralogists (Society of Sedimentary Geology) Special Publication 52, p. 111–126.